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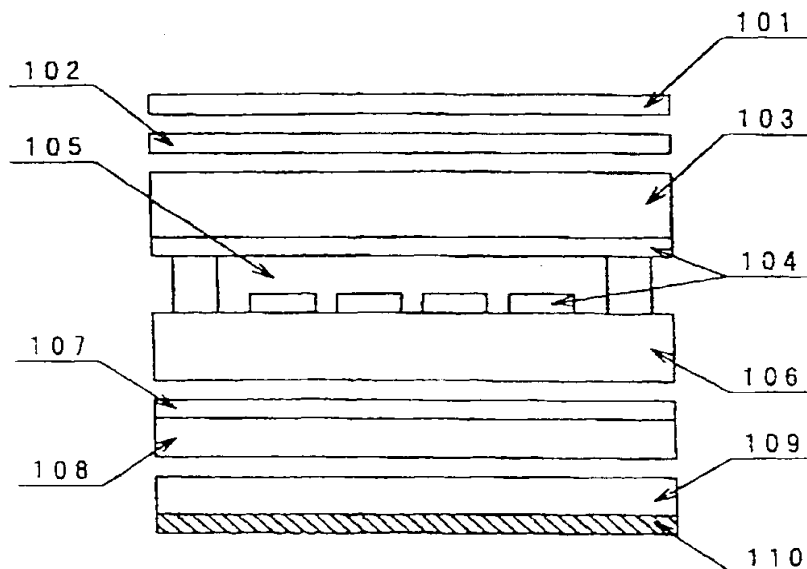
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(54) Liquid crystal display device and apparatus for using the same

(57) The object of the present invention is to provide a transreflective liquid display device which is capable of providing efficient transmissive display without damaging brightness in the reflective display. A transreflective liquid crystal display device comprising a liquid crystal panel having a liquid crystal compound (105) sandwiched between a pair of opposing substrates (103, 106) and transparent electrodes (104), a first polarizer (101) disposed on the viewer's side of said liquid crystal

panel, a reflective polarizer (108) disposed on the opposite side of the liquid crystal panel as against said first polarizer, and a backlight assembly (109, 110), wherein said reflective polarizer has the function of transmitting the polarisation component with a predetermined orientation, while transmitting the polarisation component with a different orientation and wherein said backlight assembly is substantially black in the non-emissive state.

[FIG. 1]



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Description

This invention relates to a liquid crystal display device. More specifically so-called transreflective liquid crystal display device which is capable to be switched between transmissive mode and reflective mode of display by ON and OFF of a backlight assembly. Further, the present invention relates to electronic apparatus equipped with such a liquid crystal display device as a display.

Primarily, the liquid crystal display device is a light-receiving display device and when a reflective liquid crystal display device is viewed in a dark place, it requires some supplemental lighting. Accordingly, a liquid crystal display device was devised which has a backlight assembly disposed on a back of a liquid crystal panel, the backlight assembly being used by switching between the reflective mode and the transmissive mode according to requirement. This is the so-called transreflective liquid crystal display device.

Referring to FIG. 11, a construction of a conventional transreflective liquid crystal display device is described. In FIG. 11, 1101 is an upper polarizer, 1102 a retardation film, 1103 an upper glass substrate, 1104 transparent electrodes, 1105 a liquid crystal layer, 1106 a lower glass plate, 1107 a lower polarizer, 1108 a transreflective plate, 1109 a backlight assembly. The transreflective plate 1108 is a sheet made of plastic resin within which, for example, pearl pigment beads are dispersed for reflecting 70 % and transmitting 30% of incident light (in another type reflecting 50 % and transmitting 50 %). It is switched over between the reflective and the transmissive mode by ON and OFF of the backlight assembly.

Next, referring to FIG. 12, the construction of the backlight assembly 1109 is described. In FIG. 12, 1201 and 1202 are light diffusing plates, 1203 a light guide plate, 1204 a light source, 1205 a light reflecting plate. Light scattering bodies 1206 are printed over the surface of the light guide plate. The light diffusing plates 1201 and 1202 are often used in an lamination of plural sheets as shown in this example, but sometimes it is used in only a single sheet. Also, a prism sheet may be disposed in some cases under the light diffusing plate 1201. This backlight assembly exhibits white colour in the non-emissive mode, as the light diffusing plates have whitish diffusing colour, the light guide plate being transparent, and the light reflecting plate glossy white.

However, in the aforementioned conventional transreflective liquid crystal display device, a part of light incident on the surface of the transreflective plate is transmitted through the transreflective plate, causing a problem that the display in the reflective mode becomes darker by the same amount as the light transmitted (with 50 - 70 % of brightness compared with a pure reflective liquid crystal display device). Further, the light emitted from the backlight assembly is attenuated by passing through the transreflective plate, causing display in the transmissive mode darker. As a result there is a problem that the efficiency of light utilisation becomes poor.

It is an object of the present invention to provide a liquid crystal display device which enables to offer a bright display in the transmissive mode utilising the light from the backlight assembly efficiently without damaging brightness of the display in the reflective mode.

In order to solve the aforementioned problems the liquid crystal display device of the present invention is characterised in that it comprises a liquid crystal panel made of liquid crystal sandwiched between a pair of substrates, a first polarizer disposed on the viewer's side of the liquid crystal panel, a reflective polarizer disposed on the opposite side of the liquid crystal panel as against said first polarizer, the reflective polarizer having a function of reflecting the polarisation component of the light with predetermined orientation, while transmitting the polarisation component of the light with different orientation from that, and a backlight assembly disposed on the opposite side of the reflective polarizer as against the liquid crystal panel, the backlight assembly having a light absorbing capability in the non-emissive state.

In the reflective mode, almost 100 % of the polarisation component with the predetermined orientation of the light incident from the side of the liquid crystal panel into the reflective polarizer is reflected to the side of the liquid crystal panel. Namely, when the light transmitted through the liquid crystal panel is the polarisation component of the light with the predetermined orientation, the bright display state is available, while the light different from the polarisation component with the predetermined orientation of the light incident from the side of the liquid crystal display device panel into the reflective polarizer is transmitted through the reflective polarizer to exit toward the backlight assembly which has a light absorbing capability. Namely, when the light transmitted through the liquid crystal panel is the polarisation component of light different from the predetermined orientation, a dark display state is available.

Also, in the transmissive display mode, the polarisation component different from the predetermined orientation of the light emitted from the backlight assembly passes the reflective polarizer to exit towards the liquid crystal panel, while the polarisation component with the predetermined orientation of the light emitted from the backlight assembly is reflected by the reflective polarizer toward the liquid crystal panel but a part of such light is scattered or reflected on the surface of the backlight assembly to change its orientation of polarisation and finally to pass through the reflective polarizer. Namely, most of the light emitted from the backlight assembly is transmitted through the reflective polarizer, resulting in improvement of the efficiency of utilisation of light from the backlight assembly to attain bright display in the transmissive mode.

It is preferable to use a birefringent multi-layered dielectric sheet for the reflective polarizer of the present invention.

Also, besides it, a reflective polarizer with a construction of cholesteric layers sandwiched between quarter wave plates can be employed.

Also, as a backlight assembly having light absorbing capability in the non-emissive state of the present invention, a backlight assembly including a member for emitting the light toward the direction of the reflective polarizer and a light absorbing body capable to absorb the light incident from the direction of the reflective polarizer can be employed.

In this instance, it is preferable to provide the light absorbing body on the rear of the substantially transparent light emitting member. By such construction, the light from the light emitting member can be emitted towards the reflective polarizer side without being absorbed by the light absorbing body in the transmissive display mode. In the reflective display mode, the light incident from the direction of the reflective polarizer side to the backlight assembly passes through the light emitting member to be absorbed by the light absorbing body. An embodiment of such a backlight assembly is a backlight assembly made of an EL element with the light absorbing body disposed on its rear.

Also, as a backlight assembly of the present invention having light absorbing capability in the non-emissive state, a backlight assembly including a light source, a light guide for emitting the light from the light source toward the direction of the reflective polarizer and a light absorbing body for absorbing the light incident from the direction of the reflective polarizer can be employed. In this case, it is preferable to provide the light absorbing body on the back of the light guide. By such construction, the light from the light emitting member can be emitted toward the direction of the reflective polarizer without being absorbed by the light absorbing body in the transmissive display mode. In the reflective display mode, the light incident from the direction of the reflective polarizer to the backlight assembly passes through the light guide to be absorbed by the light absorbing body. Embodiments of such backlight assemblies are those backlight assemblies made of combinations of a fluorescent tube or LED and a light guide with the light absorbing body attached on its back.

Also, organic LED, VFD(a fluorescent character display tube), LED array or a flat CRT can be employed as backlight assemblies. In those cases, they have an advantage of providing light absorbing capability without any requirement of otherwise providing a light absorbing body, because these backlight assemblies can be constructed to have the light absorbing capability in itself in the non-emissive state.

By the way, the light absorbing capability in the present invention refers to a capability to enable to absorb the light incident from the liquid crystal panel to the extent that a sufficiently dark display state is available in the reflective mode compared with the bright display state. More specifically, it is preferable that the luminance factor of the backlight assembly in the non-emissive state is 40 % or less and 20 % or less is more preferable. Further, if the colour of the backlight assembly in the non-emissive state is substantially black, the best contrast characteristic is obtained. By the way the luminance factor refers here to "a ratio of the luminance of an object to that of the perfect diffuse reflector where illumination and observation are made under the same conditions" as defined in 2 (3) of JIS Z 8722 (1982) "the Method for measuring colour of reflecting or transmissive object". Also, as the illuminating conditions, the condition c is taken which is defined in 4. 3. 1 (3) of JIS Z 8722 (1982). The condition c defines that "the specimen shall be illuminated uniformly from all directions and the reflected light in the direction forming an angle of 10 degrees or less referring to the normal line to the specimen surface shall be received".

Also, the liquid crystal display device of the present invention is characterised in that it comprises a liquid crystal panel made of liquid crystal sandwiched between a pair of substrates, the liquid crystal panel being adapted to be able to switch between a first state for reflecting the polarisation component of the light with a predetermined orientation, while transmitting the polarisation component of the light with different orientation from that and a second state for transmitting almost all of the light and a backlight assembly disposed on the back of said liquid crystal panel having a light absorbing capability in the non-emissive state.

According to the liquid crystal display device of the present invention, in the first state of the reflecting mode, it is possible to obtain the bright display state, since the polarisation component with a predetermined orientation of the light incident to the liquid crystal panel is reflected within the liquid crystal panel. In the second state of the reflecting mode, almost all of the light incident on the liquid crystal panel is transmitted through the liquid crystal panel to be emitted to the backlight assembly side. As the backlight assembly has light absorbing capability in the non-emissive state, the dark display state is obtained.

Also, in the first state of the transmissive display mode, the polarisation component with different orientation from the predetermined orientation of the light emitted from the backlight assembly passes through the liquid crystal panel, while the polarisation component of the light with the predetermined orientation is reflected by the liquid crystal panel to bring the display into the dark display state. On the other hand, in the second state almost all of the light emitted from the backlight assembly passes through the liquid crystal panel to bring the display into the bright display state.

Generally a liquid crystal panel having such display modes works to reflect the light in a range of the predetermined wave lengths and to transmit the light in a range different from the predetermined wave lengths, i.e. it exhibits a colour display in the first state of the reflecting display mode and the dark display in the second state of the reflecting display mode. Also, in the first state of the transmissive display mode, it exhibits a colour display with a different colour from that of the colour display in the first state of the reflecting mode and a white display in the second state of the transmissive

display mode.

By the way the liquid crystal panel having such display modes is described in details in SiD92 DiGEST, pp/59 - to 761

Also, an embodiment of the liquid crystal display device of the present invention comprises a liquid crystal panel made of liquid crystal sandwiched between a pair of substrates, a polarizer disposed on the viewer's side of the liquid crystal panel, a reflective polarizer disposed on the opposite side of the liquid crystal panel as against said polarizer, the reflective polarizer having a function of reflecting the polarisation component of the light with a predetermined orientation, while transmitting the polarisation component of the light with different orientation from that, and a backlight assembly disposed on the opposite side of the reflective polarizer as against the liquid crystal panel, wherein the polarisation axis of the light emitted from said liquid crystal panel can be varied corresponding to the ON and OFF of said backlight assembly.

In a liquid crystal display device employing a reflective polarizer as a reflector, the polarisation component of the light reflected by the reflective polarizer in the reflective mode has a different polarising orientation from the polarisation component of the light transmitted through the reflective polarizer in the transmissive display mode. Namely, brightness and darkness is reversed between the reflective mode and the transmissive mode.

In the present invention it is possible to prevent above mentioned reversal of brightness and darkness of a display, as the polarisation axis of the light emitted from the liquid crystal panel can be varied corresponding to ON and OFF of the backlight assembly. As a result it is possible to obtain the similar display both in the transmissive mode and the reflective mode.

More specifically, it is possible to vary the polarisation axis of the light emitted from the liquid crystal panel by employing a liquid crystal panel which is driven by applying voltage to dots formed on each of the crossing points of a plurality of data lines and a plurality of scanning lines and by varying data signals applied to the said data lines corresponding to ON and OFF of said backlight assembly.

Also, it is possible to prevent change of colour between the reflective mode and the transmissive mode even in the colour display by converting said data signals so as to make the displayed colour of ON state and that of OFF state of the backlight assembly have a relationship of the complementary colour.

Also, the electronic apparatus of the present invention is characterised in that it is equipped with any one of such liquid crystal display devices as described above as a display member. Due to the above construction it has advantages that it has reduced power consumption compared with the electronic apparatus equipped with conventional liquid crystal display devices and a brighter and easier-to-see display is obtained than that of the electronic apparatus equipped with conventional liquid crystal display devices.

Embodiments of the invention will now be described in detail, by way of example only and with reference to the accompanying drawings, in which:-

Figure 1 illustrates the main part of an embodiment of the liquid crystal display device according to the present invention.

Figure 2 illustrates the main part of an embodiment of the reflective polariser according to the present invention in accordance with example 1 to example 4.

Figure 3 illustrates an embodiment of the backlight assembly of the liquid crystal display device of the example 1 of the present invention.

Figure 4 is a drawing useful in explaining the function of the liquid crystal display device of the example 1 of the present invention.

Figure 5 illustrates the construction of the backlight assembly of the liquid crystal display device of the example 2 of the present invention, in which figure 5(a) shows a light guide plate printed with white paint, figure 5(b) shows a light guide plate with sibo (cavity), figure 5(c) shows wave-shaped light guide plate, and figure (d) shows an air light guide plate.

Figure 6 illustrates the main part of an embodiment of the liquid crystal display device in accordance with example 3 of the present invention.

Figure 7 is a perspective view illustrating the liquid crystal display device in accordance with example 4 of the present invention.

Figure 8 is a drawing illustrating the displayed colour in example 4 of the present invention.

Figure 9 is a drawing illustrating the main part of an embodiment of the liquid crystal display device in accordance with example 5 of the present invention.

Figure 10 is a drawing illustrating the appearance of electronic apparatus in the example 6 of the present invention in which figure 10(a) shows a portable telephone, figure 10 (b) shows a watch, figure 10(c) shows portable information equipment.

Figure 11 is a drawing illustrating the essential part of the construction of a conventional transfective liquid crystal display device.

Figure 12 is a drawing illustrating the construction of the backlight assembly employed in a convention transfective

liquid crystal display device

FIG. 1 is a drawing illustrating part of the construction of liquid crystal display device of the present invention. First, the construction is described. In FIG. 1, 101 is a polarizer, 102 a retardation film, 103 an upper glass substrate, 104 a transparent electrode, 105 a liquid crystal layer, 106 a lower glass substrate, 107 a light diffusing plate, 108 a reflective polarizer, 109 a light emitting member of a backlight assembly which is substantially transparent in the non-emissive state, and a hatched area of 110 is a light absorbing plate. In this instance, 101 and 102, 102 and 103, 106 and 107 are illustrated as being separated but this is just to make the drawing easy to understand and actually they are bonded with adhesives. Also, the upper glass substrate 103 and the lower glass substrate 106 is depicted to have a wide gap on the same reason but actually they are opposed to each other with a narrow gap of several μm to a dozen or so μm . By the way besides those elements shown, other elements are normal such as a liquid crystal orientation film, dielectric film, anti-glare film, spacer ball, liquid crystal driver IC, driver circuit, etc., but they are omitted as they are not especially necessary to describe the present invention.

Next, described is each element. The polarizer 101 is similar to the conventional one which works to absorb the predetermined linear polarisation component and transmit the polarisation component different from that.

The retardation film 102 is a uniaxial stretched film of polycarbonate resin especially used to compensate colouring of STN liquid crystal display device. It is often omitted in the case of TN liquid crystal display device.

The liquid crystal layer 105 is made of STN liquid crystal compound twisted in 210E - 270E but if display capacity is small, TN liquid crystal compound twisted in 90E may be used. The twist angle is determined depending on the direction of orientation alignment of upper and lower glass substrates and amount of chiral additive added to the liquid crystal.

Light scattering plate 107 can be made of embossed plastic plate or plastic plate dispersed with beads. Also, beads mixed in the adhesive layer between 106 and 108 can be used as a substitute of a light scattering plate. The light scattering plate is disposed in order to scatter reflected light of the reflective polarizer with a surface somewhat like a mirror but displaying is possible without it. Also, it can be located not only between 106 and 108 but also can be positioned adjacent to 105 or between 102 and 103 or over the 101.

A birefringent multi-layered dielectric film is employed as reflective polarizer 108. The birefringent multi-layered dielectric film works to reflect the predetermined linear polarisation component and transmit the polarisation component different from that. Such a birefringent multi-layered dielectric film is disclosed in detail in an internationally publicised international application (publication of international application number: WO97/01788) or Japanese Patent National Publication 9-506985. Also, such a reflective polarizer is generally available in the market as DBEF (trade name) from Minnesota Mining and Manufacturing Co., U.S.A.

Next, described is the structure of the reflective polarizer. FIG. 2 is a drawing illustrating the main part of the construction of the reflective polarizer. The reflective polarizer is primarily a birefringent multi-layered dielectric film comprised of two kinds of alternately laminated polymer layers 201 and 202. One of two kinds of polymer is selected from materials with high photoelasticity and another from those with low photoelasticity. On such selection care should be taken to ensure that the refractive index for the ordinary ray becomes approximately equal when both of them are stretched. For example, PEN (2,6 - polyethylene naphthalate) is selected as high photoelasticity material and coPEN (70 - naphthalate/30-terephthalate copolyester) as low photoelasticity material. Both of them are alternately laminated and stretched at a stretch ratio of about 5:1 along the direction of the x-axis of the rectangular co-ordinate system 203 of FIG. 2 and the refractive index along x-axis was at 1.88 in PEN layer and 1.64 in coPEN layer. And the refractive index along the y-axis was at about 1.64 in both PEN and coPEN layer. When a light is impinged in normal direction on the surface of the laminated film, component of light oscillating in the direction of the y-axis passes the film. This is the polarisation axis. On the other hand, light component oscillating in the direction of the x-axis is reflected only when PEN and coPEN layers meet a certain conditions. This is a reflection axis. The condition is that the sum of optical path (product of refractive index and film thickness) of PEN layer and that of coPEN layer is equal to a half wavelength of the light. By laminating such PEN layers and coPEN layers in more than several dozens or more than a hundred layers, if possible, in thickness of about 30 μm , almost all of the light component oscillating along the x-axis can be reflected. A reflective polarizer made in this manner only generate polarisation in the light with a designed single wavelength. Accordingly, by laminating a plurality of reflective polarisers with different designed wavelengths with their axes aligned, it is possible to produce a film with polarisation capability in wide range of wavelengths.

This reflective polarizer is more than 30% brighter than the reflective polarisation means which is constructed by combining a conventional reflective polarizer with an aluminium reflective plate. There are two reasons. One of the reasons is that the reflective polarizer reflects almost 100 % of the predetermined linear polarisation light while the reflectivity of metal aluminium is only a little less than 90 %. Another reason is that conventional absorption type polarisers waste some 20 % of light because they utilise halogen materials such as iodine or dichroic materials such as dye, of which dichroic ratio is not necessarily high.

Otherwise it is possible to use liquid crystal polymers which exhibit cholesteric phase for a reflective polarizer. This material reflects the predetermined circular polarised light component and passes other light component than that

Such a reflective polarizer is disclosed in detail in Japanese Unexamined Patent Publication No. 8-271892.

An EL (electroluminescent) element in FIG. 3(a), for example, can be employed as the backlight assembly 109 of FIG. 1. In FIG. 3, 301 is a glass substrate, 302 a transparent electrode, 303 a first dielectric layer, a hatched area 304 a EL emission layer, 305 a second dielectric layer, 306 a rear electrode, 307 a rear sealing glass, a hatched area 308 a light absorbing plate. A common type of the EL layer made by dispersing fluorescent powder in binder can be used but it is better to use recently-developed organic ultra-thin film as it provides better transparency. A transparent ITO is used as the rear electrode. Accordingly, the EL backlight assembly is substantially transparent in the non-emissive state. By the way, transparent polymer films such as polyester may be utilised in place of glass substrates.

In this example a light absorbing plate is disposed behind the EL backlight assembly but it may be placed in any position as long as it is behind the EL emission layer. In FIG. 3(b) it is disposed within the EL backlight assembly. In FIG. 3(b), 311 is a glass substrate, 312 a transparent electrode, 313 a first dielectric layer, a hatched area 314 a EL emission layer, 315 a second dielectric layer, 318 a light absorbing plate, 316 a rear electrode, 317 a rear sealing glass. In this case, the rear electrode 316 may be made of non-transparent metal. The light absorbing plate was obtained by laminating thin metal oxides.

Then, the function of the liquid crystal display device of the example 1 is described by referring to FIG. 4. In FIG. 4, 401 is a polarizer, 402 a retardation film, 403 an upper glass substrate, 404 a lower glass substrate, 405 a reflective polarizer, 406 a backlight assembly substantially transparent in the non-emissive state, 407 a light absorbing plate, 408 a liquid crystal in OFF state, 409 a liquid crystal in ON state.

First, the case of non-emissive state of the backlight assembly, or the case of the reflective mode is discussed. The light 411 and 412 incident from above is converted to the linear polarised light by the polarizer 401. Then, it is modulated variously by the retardation film and the liquid crystal panel but it is mostly restored to the linear polarised light when it impinges on the reflective polarizer 405. However, the linear polarised light in the area 409 where the liquid crystal panel is ON and the linear polarised light in the area 408 where it is OFF cross each other in a right angle, respectively. So that the axis of the reflective polarizer is disposed in advance so as to reflect the linear polarised light in OFF state and transmit the linear polarised light in ON state. In OFF state the liquid crystal display device is set in the bright display-mode as the linear polarised light reflected on the reflective polarizer is emitted to the upper side along the same path as above, while in ON state the liquid crystal display device is turned to the dark display mode as the linear polarised light transmitted through the reflective polarizer passes through the transparent backlight assembly 406 to be absorbed by the light absorbing body 407. When the liquid crystal display device panel is in an intermediate state between ON state and OFF state, the liquid crystal display device exhibits a half-tone display as both of them mix together.

Next, the case of emissive mode of the backlight assembly, or the case of the transmissive mode is discussed. Under the circumstance of the transmissive mode of the liquid crystal display device, it is supposed that the ambient illumination is sufficiently dark, so the light incident from above is negligible. Out of the light 413 and 414 emitted from the backlight assembly, the linear polarised light with certain orientation is reflected by the reflective polarizer, while the remainder of the linear polarised light passes through the reflective polarizer. The linear polarised light transmitted passes along the same path as in the reflective mode to exhibit bright-dark display. The reflected linear polarised light is lost by being absorbed by the light absorbing plate 407 but some of the light scattered on the surface of the backlight assembly etc. reaches the reflective polarizer again. Compared with the conventional transfective display, the liquid crystal display device of the present invention is two or three times more effective as it has no transreflector.

However, here arises one difficult problem. The linear polarised light reflected on the reflective polarizer in the reflective display mode and the linear polarised light transmitted through the reflective polarizer in the transmissive display mode are not the same but they have orientations crossing in a right angle each other. Accordingly, the brightness and darkness is reversed in the reflective display mode and the transmissive display mode. If the ambient light is sufficiently bright so as not to be negligible, the display sometimes difficult to see as both of them mix each other. Also, especially in the case of conducting the colour display by incorporating the colour filter in the liquid crystal panel, it becomes difficult to see as not only reversal of brightness and darkness but also, colour reversal takes place, too.

To solve such a problem, for example, in the monochrome display, it is effective to adopt a colour for the light of the backlight assembly quite different from that of the reflective display of the liquid crystal panel. Also, it is very effective to convert displayed data so as to reverse the display of the liquid crystal panel between the reflective mode and the transmissive mode. This method is discussed in detail in the example 4.

Then, the luminance factor of the backlight assembly of the liquid crystal display device of the present invention in the non-emissive mode discussed above was measured as follows: first, the specimens are those members located lower than reflective polarizer 108 of FIG. 1, or the light emitting member 109 and the light absorbing plate 110. These specimens are illuminated from all directions using an integration sphere to measure its luminance in the direction of the normal. A ratio of the luminance thus obtained to that of a standard white plate of barium sulfate measured likewise is the luminance factor. The result of the measurement was in the range of 17 % - 32 %. For comparison, the luminance factors of the conventional backlight assemblies were measured and they were found to be in a range of 57 % to 78 %.

%, showing that the backlight assembly used in the present invention looks fairly dark. By using such a backlight assembly the liquid crystal display device of the present invention could attain such a high degree of contrast as over 1:5 in the reflective display mode.

(Example 2)

The example 2 is another embodiment of the present invention. The construction is almost the same as the liquid crystal display device in the example 1 shown in FIG. 1 but as illustrated in FIG. 5 such backlight assemblies are used as a fluorescent tube, a LED (light emitting diode) or a light bulb in a light guide system in place of a surface light source such as an EL. In FIG. 5(a), 501 is a light guide plate, 502 a light source, a hatched area 503 is a light absorbing body and 504 light diffusing elements. A plate of acrylic resin with high transparency is used as the light guide member 501. The light diffusing elements was provided by printing white paint. As area of the light diffusing elements is so minimal that it hardly damages transparency of the light guide member. The light diffusing elements 504 may be disposed on either the front or rear surface of the light guide member 501. In arranging the light diffusing elements, the distribution density is changed with a consideration for providing uniform surface illumination. Besides a cathode ray tube, a hot cathode ray tube, LED, or an incandescent lamp can be chosen at will as a light source 502. The backlight assemblies used in the conventional transmissive liquid crystal display device uses a light reflecting plate in place of the light absorbing plate 503 and are provided with the light diffusing plate over the light guide member 501 but by constructing as shown in FIG. 5(a), the backlight assembly becomes substantially black in the non-emissive state.

By changing the density of the light diffusing elements 504 variously, the luminance factor of the backlight assembly in the non-emissive state can be changed variously. The luminance factor is measured in the same manner as in FIG. 1 and the results of the measurements are presented in table 1 with corresponding contrasts in the reflective mode.

[TABLE 1]

LUMINANCE FACTOR	CONTRAST
6.2%	8.1
9.5%	8.2
14.6%	8.0
19.1%	7.8
26.4%	7.4
32.3%	6.9
38.7%	6.3
45.6%	5.8
54.9%	4.7
61.0%	3.6
69.3%	2.1

The results of table 1 varies depending on the liquid crystal panel or illumination used but the tendency does not change. The smaller the luminance factor, the higher the contrast. The luminance factor of the conventional backlight assembly has been in the range of 57 % to 78 % but a large improvement in contrast will be available if the smaller luminance factor can be provided even in a small amount. However, if the luminance becomes less than 20 %, such effect almost reaches saturation. Accordingly, it is desirable to make the luminance factor to be at least 40 % or less, preferably 20 % or less.

FIG. 5 (b) is an example of the backlight assembly with a light guide system. 511 is a light guide plate, 512 a light source, a hatched area 513 is a light absorbing plate and 514 sibos. Sibos are a plurality of small cavities which are formed directly on the light guide by injection moulding. The light entered into the light guide emits from those cavities. This backlight assembly exhibits substantially black colour in the non-emissive state, too.

FIG. 5 (c) is also, an example of the backlight assembly with a light guide. 521 is a light guide plate, 522 a light source, 523 is a light absorbing plate and 524 wave-shaped structure. The light entered into the light guide emits through those wave-shaped structure. The wave-shaped structure is smooth enough to emit light with almost no damage on the transparency of the light guide. The light entered into the light guide emits through those wave-shaped structure. This backlight assembly exhibits substantially black colour in the non-emissive state, too.

FIG 5 (d) is also an example of the backlight assembly with a light guide in a broad sense. 531 is a light absorbing plate. 532 is a light source. In this example air works as the light guide plate. This backlight assembly exhibits substantially black colour in the non-emissive state, too. This backlight assembly has a feature of being very cheap even though it has a problem in surface uniformity of illumination.

(Example 3)

FIG 6 is a drawing illustrating the main part of the construction of the liquid crystal display device in accordance with another example of the present invention. First, the construction is described. In FIG. 6, 601 is a polarizer, 602 a retardation film, 603 an upper glass substrate, 604 a transparent electrode, 605 a liquid crystal layer, 606 a lower glass substrate, 607 a light diffusing plate, 608 a reflective polarizer, 609 a backlight assembly.

Most of the elements are the same as the liquid crystal display device in accordance with the example 1 but the backlight assembly is different. This backlight assembly has a feature that it is substantially black colour in the non-emissive state by itself. In the example 3, VFD (fluorescent character display tube) is used as a backlight assembly but such other backlight assemblies as LED array, or a flat CRT etc. can be employed. By employing such backlight assemblies the same effect is available as in the backlight assembly of the example 1 without providing a light absorbing plate in the rear.

(example 4)

The liquid crystal display device described in the above embodiment can also exhibit colour display. The following is an example:

FIG. 7 is a perspective view illustrating a liquid crystal display device in accordance with another example of the present invention. First, the construction is described. In FIG. 7, 701 is a upper polarizer, 702 an opposing substrate, 703 a liquid crystal, 704 a device substrate, 705 a light diffusing plate, 706 a reflective polarizer, 707 a light guide plate, 708 a light source, and 709 a light absorbing plate. A colour filter 710 and opposing electrodes (scanning lines) 711 are provided on the opposing substrate 702 and signal lines 712, pixel electrodes 713, and MIM devices 714 are provided on the device substrate 704. In this instance, 701 and 702, 704 and 705, 705 and 706 are illustrated as being separated but this is just to make the drawing easy to understand and actually they are bonded together with adhesives. Also, the opposing substrate 702 and the device substrate 704 are depicted to have a wide gap between them on the same reason but actually they have only a gap of several μm to a dozen or so μm . Also, FIG. 7 illustrate a portion of a liquid crystal display device and shows only 3 X 3 matrices for 9 dots which are formed by intersecting three scanning lines 711 and three signal lines 712 but actually, the liquid crystal display device has many more dots.

The opposing electrodes 711 and the pixel electrodes 713 are formed by transparent ITO, the signal lines 712 by metal Ta, and MIM devices is constructed by sandwiching dielectric film of Ta_2O_5 by metal Ta and metal Cr. The liquid crystal 703 is 90 degree twisted nematic liquid crystal and the polarisation axes of upper and lower polarizer cross at right angle each other. This is a general construction of the normally-white TN mode. Also, the colour filter 710 consists of three colours, or the three primary colours of the additive mixture of colour, i.e., red (shown by "R" in the drawing), green (shown by "G" in the drawing), and blue (shown by "B" in the drawing) arranged in the mosaic fashion.

In this example a liquid crystal display device of MIM active matrix system is presented but a passive matrix display may be employed without any damage on the effect of the present invention. In such a case the signal lines are formed by strip shaped ITO similar to the opposing electrodes without providing MIM device and pixel electrodes. Also, in place of TN mode, employed is STN mode with 180 to 270 degrees twisted liquid crystal display device. A retardation plate may be provided in order to compensate colouring of STN mode display.

As described in the example 1 reversal of brightness and darkness of the display takes place in the liquid crystal display device of the present invention. Especially, in the colour display not only reversal of brightness and darkness but also, reversal of the colour takes place, which results in a hard-to-see display. So that the data signals are converted so as to reverse display of the liquid crystal panel between the reflective display mode and the transmissive display mode.

Next, a specific method for the above conversion is presented. In the liquid crystal display device of the present invention, data signal voltages based on the data signals are provided through the signal lines 712 to the liquid crystal. The data signals used here is formed by converting the original data signals a into data signals b by a data signal conversion means. The conversion is switched by ON/OFF of the backlight assembly. Table 2 represents the conversion table.

[TABLE 2]

BACKLIGHT	DATA SIGNAL a	DATA SIGNAL b
0	0	0
0	1	1
0	2	2
0	3	3
0	4	4
0	5	5
0	6	6
0	7	7
1	0	7
1	1	6
1	2	5
1	3	4
1	4	3
1	5	2
1	6	1
1	7	0

The left column shows ON/OFF of the backlight assembly with "0" as OFF and "1" as ON. The two columns on the right show data signals representing 8 grayshade signals by integers of "0" to "7". "0" means dark, while "7" shows bright, and from "1" to "6" representing brightness of display between dark and bright. In OFF state of the backlight assembly the data signals a are not converted but in ON state all of the data signals a are reversed to get the data signals b. The conversion table is common to each dots of red, green and blue, so that such conversion attains reversal of the displayed colour (i.e., displays complementary colours). By utilising the data signals thus converted, the colour reversal, as well as darkness and brightness reversal, could be corrected simultaneously.

As one more example of the colour display described is a method to utilise STN birefringent interference. Details of the liquid crystal display device are disclosed, for example, in Japanese Unexamined Patent Publication No. 6-175125, etc. By substituting a reflective polarizer for a lower polarizer and a reflector of such liquid crystal display device as above and disposing such backlight assemblies as shown in FIG. 5 behind it, a transfective liquid crystal display device which is bright in both the reflective and transmissive mode is available. This liquid crystal display device as it is now also has a problem that the transmissive display is reversed. Thus, it is necessary to convert the data signals to correct the display. Table 3 shows the conversion table for it.

[TABLE 3]

BACKLIGHT	DATA SIGNAL a	DATA SIGNAL b
0	0	0
0	1	1
0	2	2
0	3	3
0	4	4
0	5	5
0	6	6
0	7	7

[TABLE 3] (continued)

BACKLIGHT	DATA SIGNAL a	DATA SIGNAL b
1	0	1
1	1	0
1	2	5
1	3	6
1	4	7
1	5	2
1	6	3
1	7	4

The left column shows ON/OFF of the backlight assembly with "0" as OFF and "1" as ON. The two columns on the right show the data signals representing 8 grayshade signals by integers of "0" to "7". In the colour display utilising STN birefringent interference, the displayed colour changes depending on the grayshade signals. FIG. 8 is a drawing for illustrating the relationship between the grayshade signals and the displayed colour on the chromaticity co-ordinates of CIE 1931 XYZ colour display system. "0" corresponds to white in the displayed colours. "1" to black, "2" to red, "3" to magenta, "4" to blue, "5" to cyan, "6" to green, and "7" to yellow. In OFF state of the backlight assembly the data signals a are not converted but in ON state the data signals a are converted so as to display complementary colours of the data signals a to get the data signals b. This conversion is not a simple reversal as shown in Table 2. By utilising the data signals thus converted, the colour reversal, as well as darkness and brightness reversal, could be corrected simultaneously.

(Example 5)

FIG. 9 is a drawing illustrating the main part of the construction of the liquid crystal display device of another example of the present invention. First, the construction is described. In FIG. 9, 901 is an upper glass substrate, 902 transparent electrodes, 903 a chiral nematic liquid crystal layer, 905 a light emitting member of a backlight assembly which is substantially transparent in the non-emissive state, and 906 or a hatched area is a light absorbing plate.

The chiral nematic liquid crystal layer 903 was prepared by mixing polymer, if necessity, to a liquid crystal of which pitch is adjusted so as to exhibit selective reflection in the visible light range. Application of voltage pulse having certain pulse height causes this liquid crystal layer to turn into a state to reflect a predetermined circularly polarised light component and transmit the polarised light component different from that. Application of voltage pulse having other pulse height causes this liquid crystal layer to turn into a transparent state with very weak diffusion. Such a liquid crystal mode is disclosed in detail in SID92 DIGEST, pp. 759-761.

As a backlight assembly 905 and 906, such ones can be used as EL discussed in the example 1 or a fluorescent tube, a LED or a light bulb etc. in the light guide system discussed in the example 2. Also, the backlight assembly discussed in the example 3 may be used which is substantially black in the non-emissive state by itself.

Next, the function of the liquid crystal display device of the example 5 is described. In FIG. 9, first, a case of non-emissive state of the backlight assembly 905, i.e., a case of reflective display mode is discussed. Of light incident from the upper direction, in the ON state of the liquid crystal panel, the circularly polarised light component in certain wavelength range having a certain orientation is reflected, while the rest of the polarised light component is transmitted. The transmitted polarised light component is absorbed by the light absorbing plate 906, while the reflected polarised light component reaches the observer, exhibiting a glittering colour display (green, for example). In the OFF state of the liquid crystal panel, all the light is transmitted and absorbed by the light absorbing plate, exhibiting a black display.

Next, the case of emissive mode of the backlight assembly, or the case of the transmissive mode is discussed. Under the circumstance of the transmissive mode of the transmissive liquid crystal display device, the ambient illumination is supposed to be sufficiently dark so the light incident from above is negligible. Out of the light emitted from the backlight assembly 905, in the ON state of the liquid crystal panel, the circularly polarised light component having one orientation within a certain wavelength range is reflected, while the rest of the polarised light component is transmitted to reach the observer, exhibiting a colour display (purple, for example). In the OFF state of the liquid crystal panel, the light of the backlight assembly is transmitted intact and, exhibiting a bright display (white, for example).

In the example 5, there is a similar problem as the example 1 that the brightness and darkness, as well as colour is reversed in the reflective display mode and the transmissive display mode. Accordingly, also, in this case, it is effective

to adopt a quite different colour for the light of the backlight assembly from that of the reflective display of the liquid crystal panel.

(Example 6)

Three examples of electronic apparatus using liquid crystal display devices as described above are shown in Figure 10. The liquid crystal display device of the present invention is suitable to such portable equipment as used under various environments and required to have low power consumption.

FIG. 10 (a) is a portable telephone with a display part 1002 on the upper part of the body 1001. The portable telephone can be used under all kinds of environments irrespective of in-door or out-door. Besides, it is required that its battery should be able to work for at least more than 200 hours in stand-by mode. Accordingly, the transreflective liquid crystal display device which can utilise the reflective display mode with low power consumption as its primary mode and which can be switched to the transmissive mode utilising a supplemental light, if necessary, is most preferable for the display device to be used on a portable telephone. The liquid crystal display device of the present invention is brighter and sharper both in the reflective mode and in the transmissive mode than the conventional transreflective liquid crystal display device.

FIG. 10 (b) is a watch with a display part 1004 on the centre of the body 1003. In application for watch it is important to be fashionable. By changing the colour of the backlight assembly, the liquid crystal display device of the present invention enables to enjoy various colour in transmissive mode without damaging easiness in looking reflective display. In design work it is advantageous to be capable to make various colour display in accordance with appearance.

FIG. 10 (c) is a portable information equipment with a display member 1006 on the upper part of the body 1005 and an input member 1007 on the lower part of the body 1005. The portable information equipment is often has touch keys in the front of the display member so that the display tends to become dark. Accordingly, the reflective liquid crystal display device or the transmissive liquid crystal display device has mainly been used usually. However, there is a problem that the former is not visible in the dark and the latter with high power consumption has short battery life. The liquid crystal display device of the present invention is suitable even for such application and it is possible to make bright display with low power consumption and it is possible to be seen even in the dark, if the backlight assembly is lit.

As afore-described, the present invention can provide a transreflective liquid display device which is capable to make efficient transmissive display without damaging brightness in the reflective display.

Claims

1. A liquid crystal display device comprising:

- a liquid crystal panel having a liquid crystal material sandwiched between a pair of substrates;
- a first polarizer disposed on the viewer's side of said liquid crystal panel;
- a reflective polarizer disposed on the opposite side of said liquid crystal panel as compared with said first polarizer, said reflective polarizer reflecting the polarisation component of light with a predetermined polarisation orientation, while transmitting the polarisation component of light with a different polarisation orientation;
- and
- a backlight assembly disposed on the opposite side of said reflective polarizer as compared with the liquid crystal panel, said backlight assembly having a light absorbing capability in the non-emissive state.

2. A liquid crystal display device as claimed in claim 1, wherein said backlight assembly has a luminance factor of 40 % or less in the non-emissive state.

3. A liquid crystal display device as claimed in claim 1 or claim 2, wherein said backlight assembly includes a member for emitting light in the direction of said reflective polarizer and a light absorbing body capable of absorbing light incident from the direction of said reflective polarizer.

4. A liquid crystal display device as claimed in claim 1 or claim 2, wherein said backlight assembly includes a light source, a light guide for emitting light from said light source in the direction of said reflective polarizer and a light absorbing body capable of absorbing light incident from the direction of said reflective polarizer.

5. A liquid crystal display device comprising:

- a liquid crystal panel having a liquid crystal material sandwiched between a pair of substrates and adapted to

be switchable between a first state and a second state, the first state for reflecting the polarisation component of light having a predetermined polarisation orientation while transmitting the polarisation component of light having a different polarisation orientation and a second state for transmitting almost all of the light, and a backlight assembly disposed on the back of said liquid crystal panel, said backlight assembly having a light absorbing capability in the non-emissive state.

6. A liquid crystal display device comprising:

a liquid crystal panel having a liquid crystal material sandwiched between a pair of substrates;
a first polarizer disposed on the viewer's side of said liquid crystal panel;

a reflective polarizer disposed on the opposite side of said liquid crystal panel as compared with said first polarizer, said reflective polarizer reflecting the polarisation component of light having a predetermined polarisation orientation, while transmitting the polarisation component of light having a different polarisation orientation; and

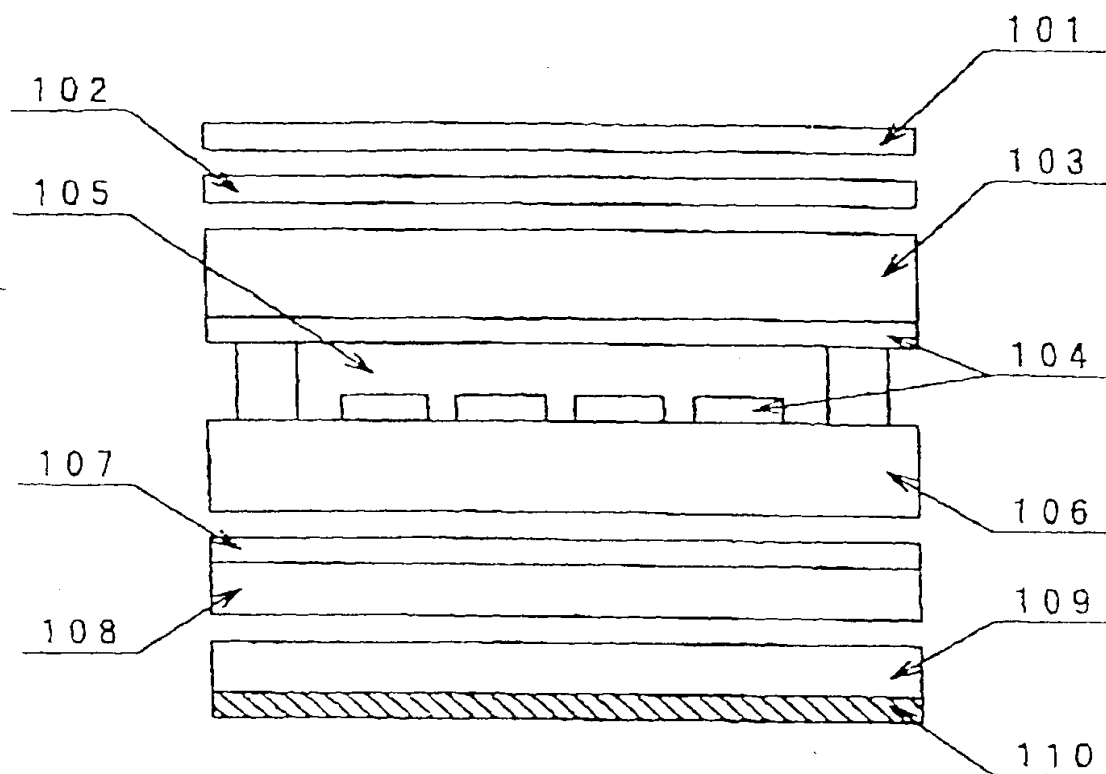
a backlight assembly disposed on the opposite side of said reflective polarizer as compared with said liquid crystal panel, wherein the polarisation axis of the light emitted from said liquid crystal panel can be varied corresponding to the ON and OFF states of said backlight assembly.

7. A liquid crystal display device as claimed in claim 6, wherein the liquid crystal panel is a liquid crystal panel driven by applying voltage to dots formed on each of the crossing points of a plurality of data lines and a plurality of scanning lines, wherein the polarising axis of the light emitted from said liquid crystal panel is varied by converting data signals applied to the said data lines corresponding to the ON and OFF states of said backlight assembly.

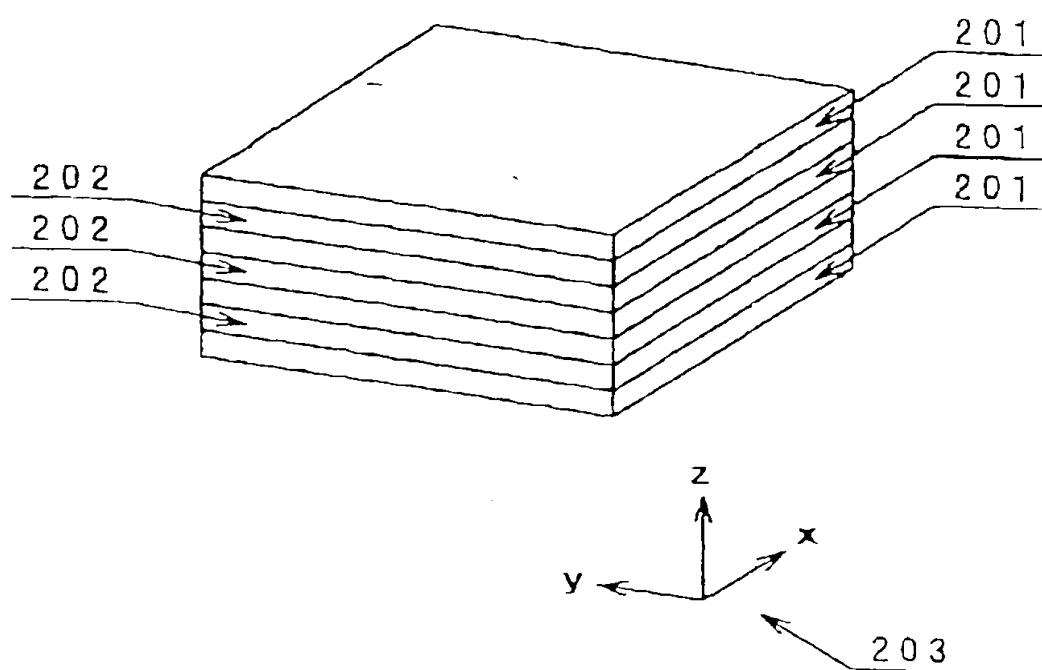
8. A liquid crystal display device as claimed in claim 7, wherein said data signals are converted so as to make the displayed colour in the ON state and the displayed colour in the OFF state of the backlight assembly have a relationship of complementary colour to each other.

9. An electronic apparatus including a display part comprising a liquid crystal display device as claimed in any preceding claim.

[FIG. 1]

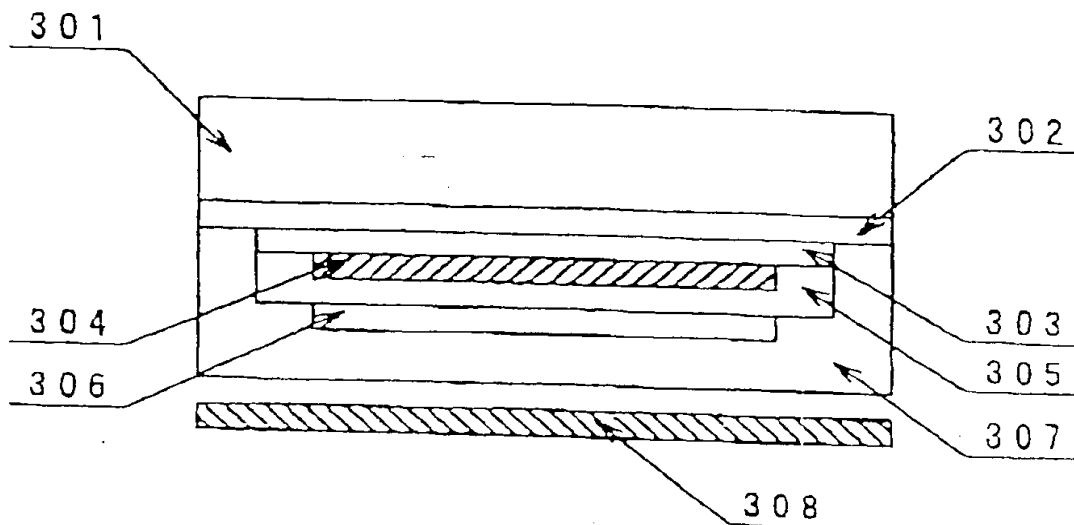


[FIG. 2]

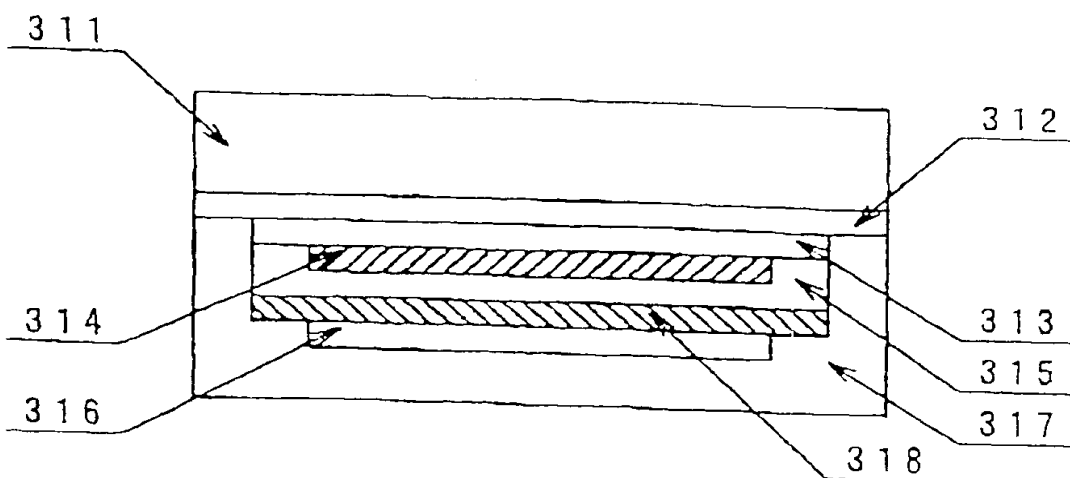


[FIG. 3]

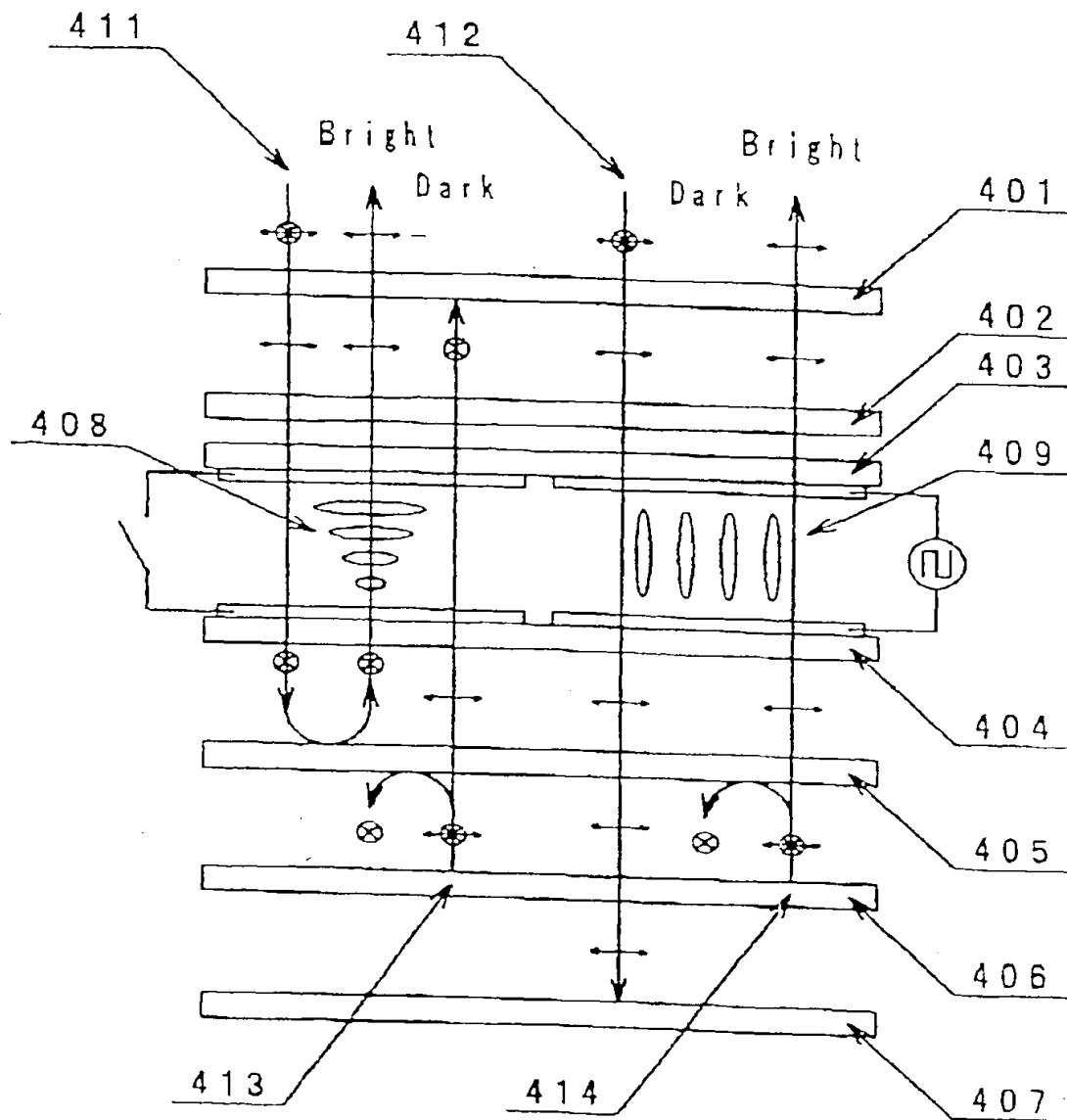
(a)



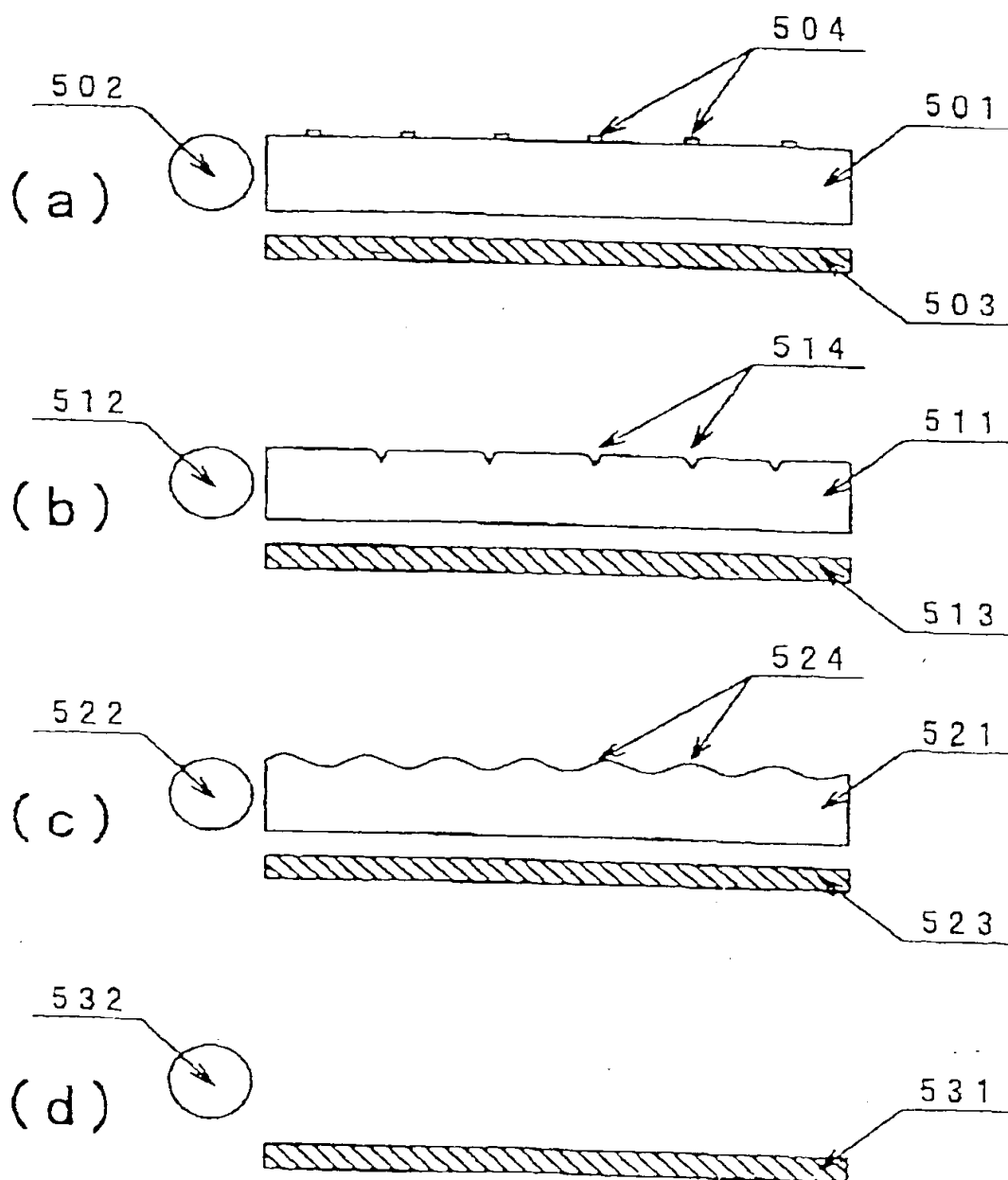
(b)



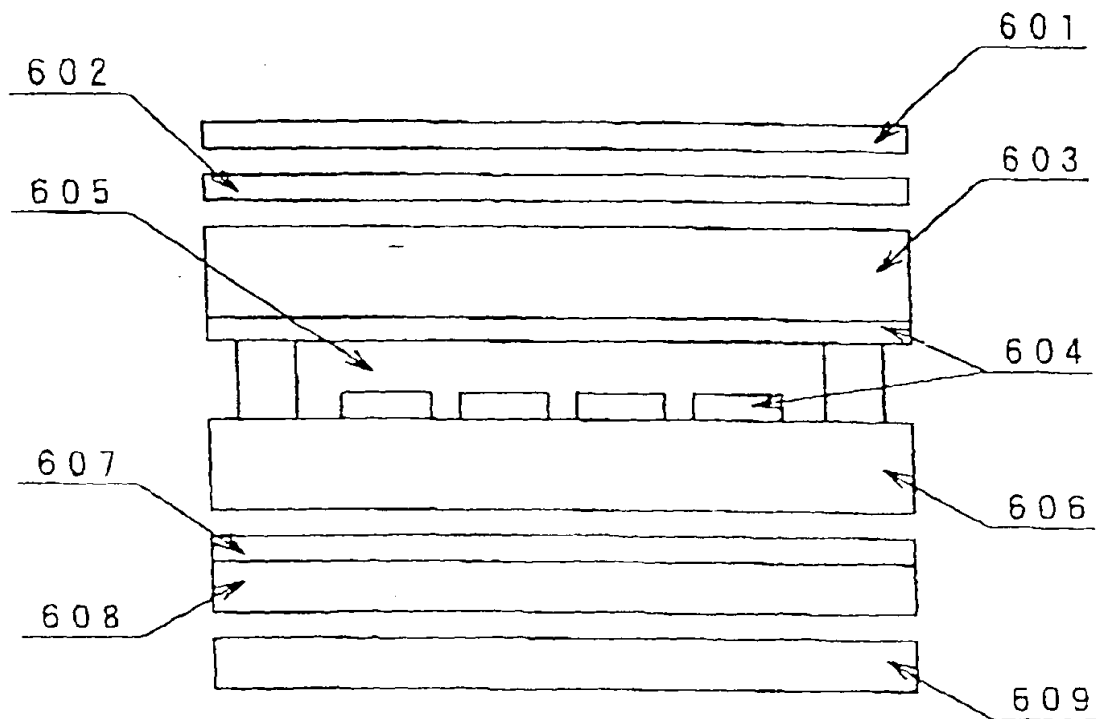
[FIG. 4]



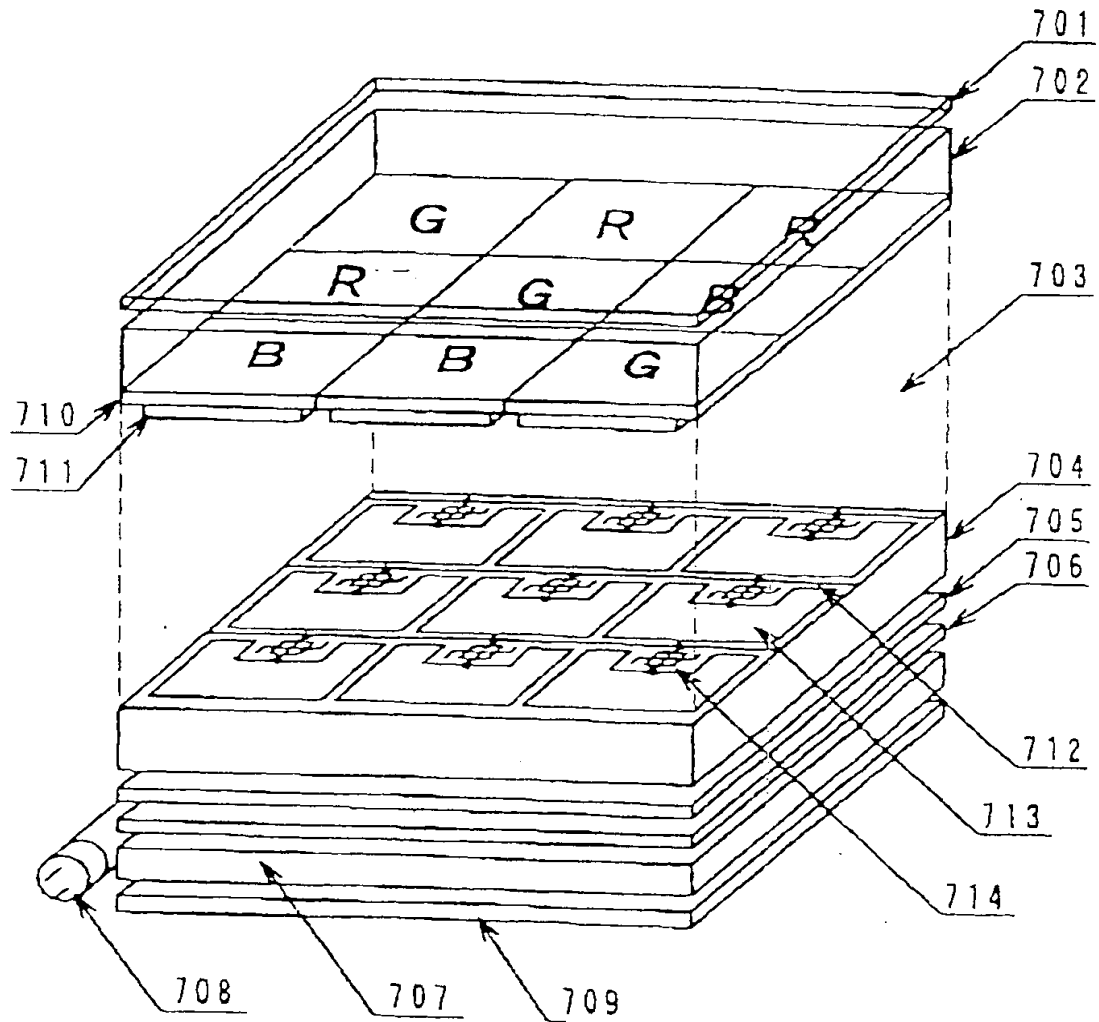
[FIG. 5]



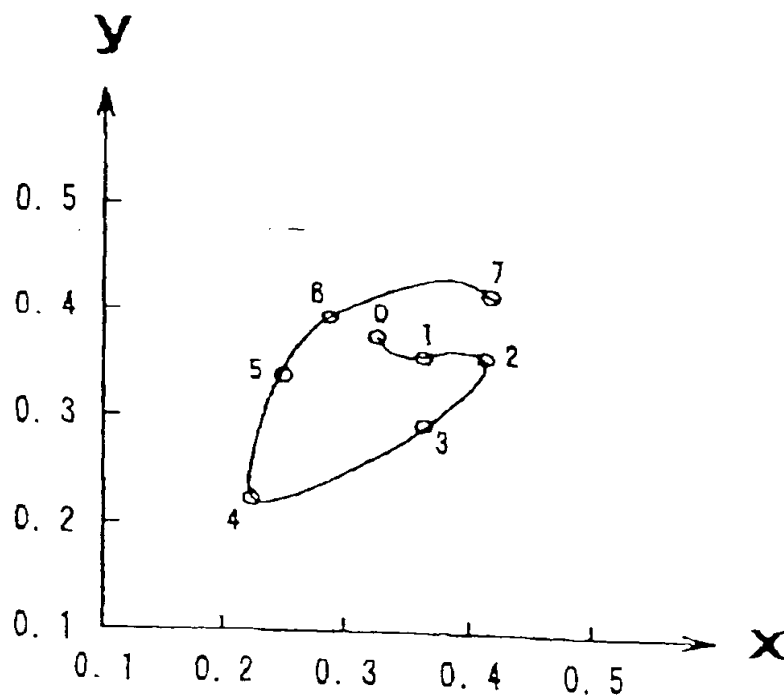
[FIG. 6]



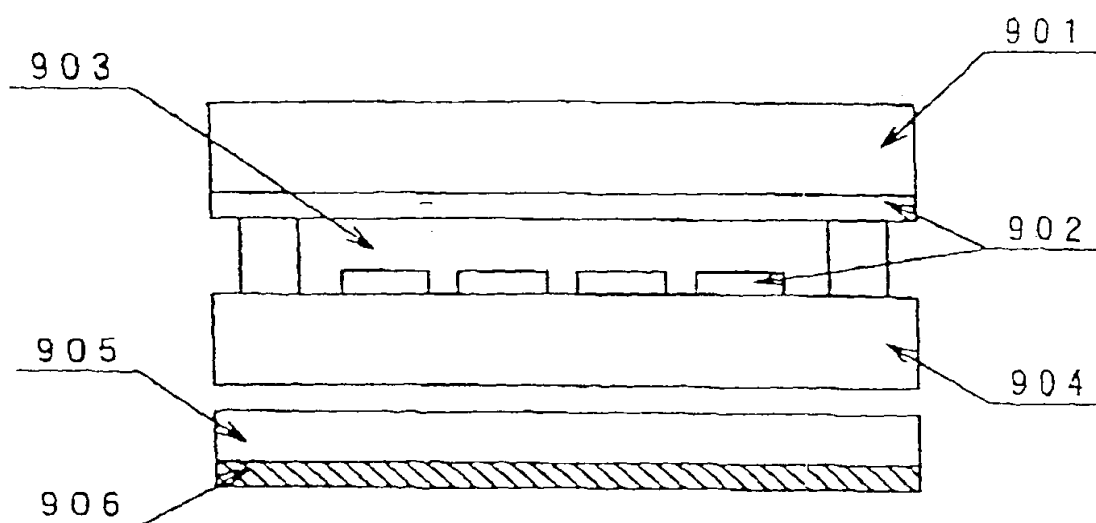
[FIG. 7]



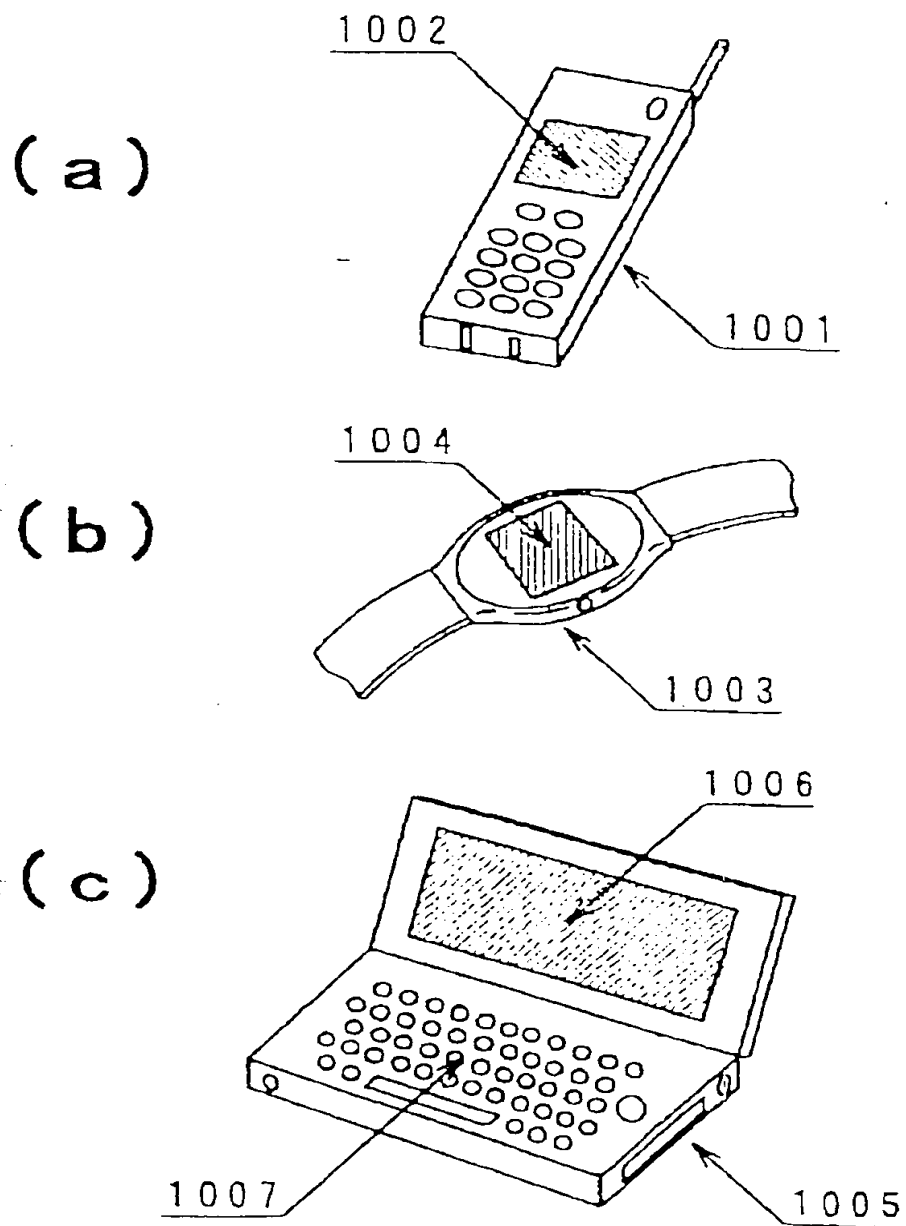
[FIG. 8]



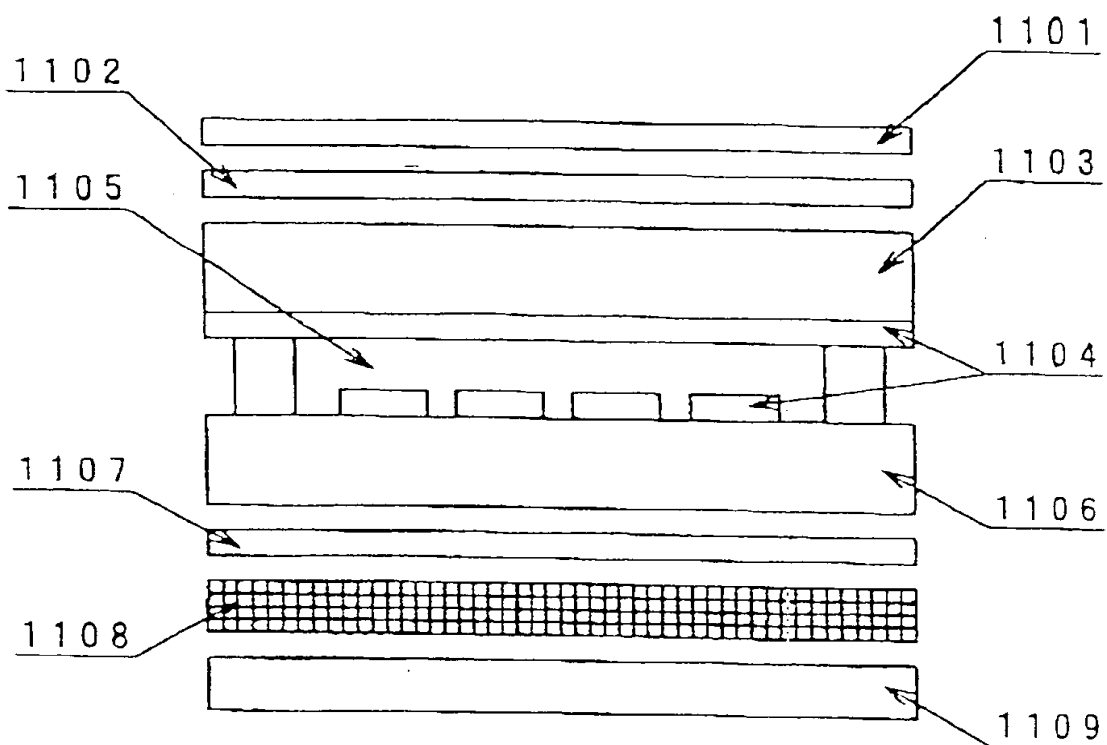
[FIG.9]



[FIG. 10]



[FIG. 11]



[FIG. 12]

